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2015 J. Phys.: Conf. Ser. 590 012057

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## Reaction dynamics studies for the system ${}^7\text{Be}+{}^{58}\text{Ni}$

D Torresi<sup>1,2</sup>, M. Mazzocco<sup>1,2</sup>, L Acosta<sup>3</sup>, A Boiano<sup>4</sup>, C Boiano<sup>5</sup>, A Diaz-Torres<sup>6</sup>, N Fierro<sup>1</sup>, T Glodariu<sup>7</sup>, L Grilj<sup>3</sup>, A Guglielmetti<sup>5,8</sup>, N Keeley<sup>9</sup>, M La Commara<sup>4,10</sup>, I Martel<sup>3</sup>, C Mazzocchi<sup>11</sup>, P Molini<sup>1,2</sup>, A Pakou<sup>12</sup>, C Parascandolo<sup>1,2</sup>, V V Parkar<sup>3</sup>, N Patronis<sup>12</sup>, D. Pierroutsakou<sup>4</sup>, M Romoli<sup>4</sup>, K. Rusek<sup>13</sup>, A M Sanchez-Benitez<sup>3</sup>, M Sandoli<sup>4,10</sup>, C Signorini<sup>1,2</sup>, R Silvestri<sup>4,10</sup>, F Soramel<sup>1,2</sup>, E Stiliaris<sup>14</sup>, E Strano<sup>1,2</sup>, L. Stroe<sup>7</sup>, and K. Zerva<sup>12</sup>

<sup>1</sup>Dipartimento di Fisica e Astronomia, Universit'a di Padova, Italy

<sup>2</sup>INFN - Sezione di Padova, Italy

<sup>3</sup>Departamento de Física Aplicada, Universidad de Huelva, Spain

<sup>4</sup>INFN - Sezione di Napoli, Italy

<sup>5</sup>INFN - Sezione di Milano, Italy

<sup>6</sup>ECT, Villazzano (TN), Italy

<sup>7</sup>NIPNE - Magurele, Romania

<sup>8</sup>Dipartimento di Fisica, Universit'a di Milano, Italy

<sup>9</sup>Department of Nuclear Reactions, INS, Warszawa, Poland

<sup>10</sup>Dipartimento di Scienze Fisiche, Universit'a di Napoli, Italy

<sup>11</sup>Faculty of Physics, University of Warsaw, Warszawa, Poland

<sup>12</sup>Department of Physics and HINP, University of Ioannina, Greece

<sup>13</sup>Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

<sup>14</sup>Department of Physics, University of Athens, Greece

E-mail: domenico.torresi@lns.infn.it

### Abstract.

The study of reactions induced by exotic weakly bound nuclei at energies around the Coulomb barrier had attracted a large interest in the last decade, since the features of these nuclei can deeply affect the reaction dynamics. The discrimination between different reaction mechanisms is, in general, a rather difficult task. It can be achieved by using detector arrays covering high solid angle and with high granularity that allow to measure the reaction products and, possibly, coincidences between them, as, for example, recently done for stable weakly bound nuclei [1, 2]. We investigated the collision of the weakly bound nucleus  ${}^7\text{Be}$  on a  ${}^{58}\text{Ni}$  target at the beam energy of 1.1 times the Coulomb barrier, measuring the elastic scattering angular distribution and the energy and angular distributions of  ${}^3\text{He}$  and  ${}^4\text{He}$ . The  ${}^7\text{Be}$  radioactive ion beam was produced by the facility EXOTIC at INFN-LNL with an energy of 22 MeV and an intensity of  $\sim 3 \times 10^5$  pps. Results showed that the  ${}^4\text{He}$  yield is about 4 times larger than  ${}^3\text{He}$  yield, suggesting that reaction mechanisms other than the break-up mostly produce the He isotopes. Theoretical calculations for transfer channels and compound nucleus reactions suggest that complete fusion accounts for  $(41 \pm 5\%)$  of the total reaction cross section extracted from optical model analysis of the elastic scattering data, and that  ${}^3\text{He}$  and  ${}^4\text{He}$  stripping are the most populated reaction channels among direct processes. Eventually estimation of incomplete fusion contributions to the  ${}^{3,4}\text{He}$  production cross sections was performed through semi-classical calculations with the code PLATYPUS [3].



## 1. Introduction

The study of reactions induced by stable and unstable weakly bound nuclei at energies around the Coulomb barrier had attracted a large interest in the last decades, since the features of these nuclei can deeply affect the reaction dynamics. Several review papers have been recently published on this topic [1, 2, 4]. The discrimination between different reaction mechanisms is in general a rather difficult task. It can be achieved by using detector arrays covering high solid angle and with high granularity that allow to measure the reaction products and, possibly, coincidences between them. The radioactive and weakly-bound  ${}^7\text{Be}$  nucleus has been chosen as subject of our investigation since it has a low particle emission threshold ( $S_\alpha=1.586$  MeV) and a very well pronounced  ${}^3\text{He}$ - ${}^4\text{He}$  di-nuclear cluster structure. Both of the constituent clusters, that are the main reaction products, are stable charged particles having similar masses. This fact makes easier the study of the interplay of different reaction mechanisms since the detection of the reaction products are easily detectable. In fact, the experimental set-up would be more complex for reactions requiring the detection of neutrons. The  ${}^7\text{Be}$  nucleus was already studied in two works. In the first study [5] the fusion and transfer-breakup cross sections were measured at five different energies for the system  ${}^7\text{Be}+{}^{238}\text{U}$ . In the second study [6], the total reaction cross section was extracted at five energies measuring the elastic scattering angular distribution for the system  ${}^7\text{Be}+{}^{58}\text{Ni}$ .

In our experiment we measured the elastic scattering angular distributions in order to extract the total reaction cross-section and we were able, for the first time, to detect and identify the  ${}^3\text{He}$  and  ${}^4\text{He}$  reaction products for the system  ${}^7\text{Be}+{}^{58}\text{Ni}$ , allowing a deeper understanding of the contribution of direct and indirect reactions at energies below the barrier.

## 2. The experiment

The experiment was performed at the Laboratori Nazionali di Legnaro-INFN in Italy. The  ${}^7\text{Be}$  beam was produced with the in-flight technique by means of the facility EXOTIC [7]. A  ${}^7\text{Li}$  primary beam delivered by the XTU tandem accelerator at 34.2 MeV beam energy and with an intensity of about 100 pA was impinging on a  $\text{H}_2$  cryogenic gas target. The  ${}^7\text{Be}$ , produced through the reaction  $p({}^7\text{Li}, {}^7\text{Be})n$ , was selected by means of a  $30^\circ$ -bending magnet and a 1 m long Wien filter and was delivered at the target position with an energy of  $22.3\pm0.4$  MeV, an intensity of  $2\text{--}3\times10^5$  pps and a purity  $\sim100\%$ . A second energy  $17.7\pm0.5$  MeV, was obtained by inserting a degrader along the beam line. These energy values correspond to approximately  $+10\%$  and  $-10\%$  of the nominal Coulomb barrier for the reaction on a  $1\text{ mg/cm}^2$  thick  ${}^{58}\text{Ni}$  target.

The detection system used was DINEX [8]. It consisted of eight Double Sided Silicon Strip Detectors (DSSSDs) arranged in 4  $\Delta\text{E}$ -E ( $45+1000\text{ }\mu\text{m}$ ) telescopes placed at angles:  $+57^\circ$ ,  $+128^\circ$ ,  $-61.5^\circ$ ,  $-132^\circ$ .

## 3. Result

In Fig. 1 the angular distributions for the scattering of  ${}^7\text{Be}+{}^{58}\text{Ni}$  are shown in linear scale. Due to the beam energy resolution and the energy loss in the  ${}^{58}\text{Ni}$  target it was not possible to distinguish between the elastic scattering and the inelastic scattering from the first excited states at 0.429 and 1.414 MeV, therefore the scattering cross-section is the quasi-elastic cross-section.

The angular distribution was fitted within the framework of the optical model with the subroutine SFresco of the main code Fresco [3], in order to extract the total reaction cross section. The out-coming theoretical curve is displayed with a solid line in Fig. 1. The total reaction cross section value obtained is 561 mb, that is in fairly good agreement with the data measured at lower beam energies in Ref. [6]. The quasi-elastic scattering data collected at 17.7 MeV beam energy (already measured by Aguilera and collaborators [6]), were substantially used to provide a further cross-check of the data normalization procedure at forward angles, while

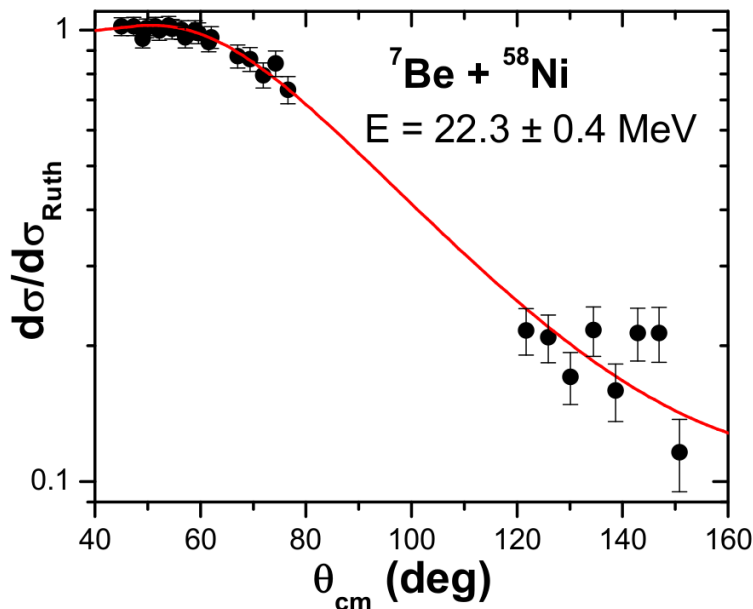


Figure 1.

the statistics of the data collected at backward angle was not enough to extract an angular distribution and just an overall ratio-to-Rutherford was evaluated.

A large  ${}^3\text{He}$ ,  ${}^4\text{He}$  yields was observed both at forward and backward angles. Several reaction mechanisms can account for the presence of  ${}^3\text{He}$  and  ${}^4\text{He}$  ions. Anyway, the only process producing at the same time a  ${}^3\text{He}$  and  ${}^4\text{He}$  is the breakup. Since the  ${}^4\text{He}$  yield is a factor of four (at least) larger than that of  ${}^3\text{He}$ , we can argue that the exclusive breakup cannot be responsible for the whole  ${}^4\text{He}$  yields. A possible source of  ${}^4\text{He}$  is the fusion-evaporation process. We used the code PACE2 to evaluate the expected angular distribution and the multiplicity of  ${}^4\text{He}$  in the fusion-evaporation of  ${}^7\text{Be}+{}^{58}\text{Ni}$  at 22.3 MeV beam energy. The theoretical curve was normalized to the average value of the measured  ${}^4\text{He}$  cross section at the most backward angles, corresponding to the range between  $40^\circ$  and  $50^\circ$ . The overall fusion cross section evaluated was  $229 \pm 29$  mb that corresponds to  $41 \pm 5\%$  of the total reaction cross section extracted from the measurement of the quasi-elastic scattering cross section. However the  ${}^4\text{He}$  coming from the fusion-evaporation process does not exhausted the total  ${}^4\text{He}$  yield.

DWBA calculations showed that  ${}^4\text{He}$  and  ${}^3\text{He}$  stripping give a significant contribution in the  ${}^3\text{He}$  and  ${}^4\text{He}$  yields at forward angles.

#### 4. Conclusions

In summary, we have studied the collisions  ${}^7\text{Be}+{}^{58}\text{Ni}$  at energy close to the Coulomb barrier using a radioactive beam produced at the facility EXOTIC. The measurements of the quasi-elastic cross section angular distribution allowed the extraction of the total reaction cross section, which is in rather good agreement with the data trend individuated in [6]. Fairly large  ${}^3\text{He}$  and  ${}^4\text{He}$  production yields were observed at the higher beam energy and for the first time we were able to unambiguously distinguish the two helium isotopes in a  ${}^7\text{Be}$ -induced experiment.

Detailed theoretical and kinematic calculations together with the exploited similarity with the system  ${}^7\text{Be}+{}^{238}\text{U}$  suggest that  ${}^3\text{He}$  and  ${}^4\text{He}$  are mainly originated by  ${}^4\text{He}$  and  ${}^3\text{He}$  stripping,

respectively.

### Acknowledgements

This work was partly supported by the Italian MIUR within the project RBFR08P1W2.001 (FIRB 2008).

### References

- [1] LF Canto PRS Gomes R D and Hussein M 2006 *Phys. Rep.* **424** 1
- [2] Keeley N *et al.* 2006 *Phys. Rep.* **424** 1
- [3] Thompson I 1998 *Comput. Phys. Rep.* **2** 167
- [4] Mazzocco M 2010 *Int. J. Modern Phys. E* **19** 977
- [5] Raabe R *et al.* 2006 *Phys. Rev. C* **74** 044606
- [6] Aguilera E *et al.* 2009 *Phys. Rev. C* **79** 021601
- [7] Farinon F *et al.* 2008 *Nucl. Instrum. Meth. B* **266** 4097
- [8] Sanchez-Benitez A *et al.* 2005 *J. Phys. G* **31** 1935